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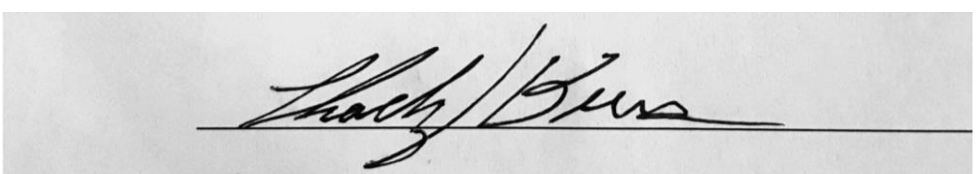

# BRAIN MECHANISMS FOR THE COGNITIVE EFFECTS OF DUAL TASK INTERFERENCE

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# A PILOT STUDY: BRAIN MECHANISMS FOR THE COGNITIVE EFFECTS OF DUAL TASK INTERFERENCE

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# ABSTRACT

Our ability to multitask has been found to have critical limitations primarily due to the restricted available attentional resources. Although many studies have explored the phenomena of processing bottleneck using serial reaction time experimental designs, there has been a significant limitation in the current literature due to the complex nature of multiple task representations. In other words, it is difficult to relate the discrepancy in performances during one-task and two-task solely to the differences in the task representation mechanisms because of the convoluted interaction between the single task and dual task experiments. To minimize such discrepancy, Schumacher *et al*. (2018) introduced a novel dual-task procedure that uses constant stimuli for one-task and two-task conditions. This study expanded the work by Schumacher *et al*. by replicating the experimental design to observe similar performance trends that show greater effects of dual-task interference in the two-task condition compared to that in the one-task condition. This finding set the stage for functional data collection that will occur following the current study using neuroimaging techniques to identify the neural correlates responsible for the facilitation of multitasking.

# INTRODUCTION

*Dual-Task Interference*

Multitasking in our daily life is the norm, and, most of the times, we choose to multitask. Whether it is talking on the phone while driving or scanning our emails while watching the television, we often make the conscious choice of performing multiple tasks at once as we believe it is the most efficient way to increase our productivity. With the increased access to affordable digital devices in the recent years, now 77% of Americans own smartphones, which is a significant hike from 35% in 2011 (Pew Research Center report, 2018). The temptation to multitask has been more serious than ever before.

Our minds, however, is not designed to perform heavy-duty multitasking. Whenever we believe to perform more than one tasks simultaneously, we actually switch between tasks in rapid succession (Alzahabi & Becker, 2013). The cognitive task of handling multiple tasks at once, thus, results in a decrease in our performance, and this phenomenon is called dual-task interference. Many researchers (e.g. Pashler, 1998) relate dual-task interference to the bottleneck theory which states that individuals have a limited amount of attentional resources allocated for parallel processing of information. Upon completing simultaneous tasks, the individuals utilize filtering of stimuli so that only the crucial information is perceived by the brain.

In 1963, Deutsch and Deutsch claimed that the bottleneck effect occurs after the full analysis of all stimuli with the most relevant stimuli determining response. However, there is an increasing supporting evidence (Treisman & Riley, 1060; Bentin *et al*., 1995; Li *et al*., 2011) for Broadbent (1958) who had argued that individuals rather experience the bottleneck effect early in the information processing mechanism and that unattended stimuli are not analyzed at all.

Expanding upon Broadbent's claims, Knoeferle *et al*. (2016) found that when participants were asked to find items while listening to sounds associated with the items, their performances was faster than when they performed the same task while listening to irrelevant sound. Knoeferle *et al*., thus, observed that activation of the bottleneck effect in the early stages of input processing gives rise to cross-modal attention that coordinates attention across two or more sense modalities such as vision and hearing.

People have difficulty performing two tasks at once even when the tasks are from different modalities (e.g. auditory or visual). Performing multiple tasks at once can overload the limited attentional resources stemming from structural capacity limitation, and the magnitude of the overload is determined by the nature of the tasks. According to Shiffrin and Schneider (1977), if the tasks require controlled processes that involve attention, although individuals are limited in their capacities to successfully perform such tasks, they can be completed quite flexibly. For example, a person who just learned how to drive, perhaps, needs to think through each step of starting a car (e.g. inserting the key, rotating the key), but if new information is presented (e.g. turn on the headlights at night), the person will be able to adequately adjust their controlled processes to account for the new information. In contrast, if the tasks require automatic processes that do not utilize attention, there is no capacity limitation, but the individuals lack flexibility once the processes are learned. This could be seen in a driver who had been driving for years but only during the day. For this person, starting a car will be an automatic process; the person does not need to think through each step. Therefore, when presented with new situation (e.g. driving at night), the person may not be able to easily fix the automated actions to incorporate the novel required action (e.g. turning on the headlights).

Utilization of controlled processes are evident in dual-task interference. Pashler (1994) argued that dual tasks activate a “stubborn bottleneck” that slows down the cognitive processes with the actions involving decision-making and memory retrieval skills. Recent studies have primarily utilized serial reaction time (SRT) tasks that require the response to two discrete tasks to gain insight about the effects of dual-task interference on sequential learning. SRT tasks involve measurements of reaction time (RT) and accuracy in given sequenced information, and significant changes in such measurements can reveal our cognitive limitations in parallel processing of multiple tasks (Schwarb & Schumacher, 2012). However, due to the complex interaction between one-task and two-task experiments, there has been a significantly difficulty in current literature to collect and analyze the experimental data to demonstrate the effects of dual-task interference. This interaction primarily resulted from using two different task representations for the one-task and two-task mapping conditions.

To address this complication, Schumacher *et al*. (2018) introduced an alternative dual-task procedure to minimize such interaction effects by using an identical set of stimuli of the same visual modality across different conditions while varying the number of “tasks” for each condition. Participants represented the visual stimuli—that each consisted of two distinct images—and the responses—that required either unimanual or bimanual coordination—during the experiment. For the one-task condition, the participants interpreted the pair of images as a unique mapping for both hands, and for the two-task condition, they interpreted each image from the pair as a unique mapping for each hand. There were strikingly different results across the conditions despite the similarity in stimuli and responses in the two conditions. The participants made faster unimanual responses than bimanual ones during the two-task condition whereas they produced faster bimanual responses than unimanual ones during the one-task condition. The researchers concluded that the reduced performance in the bimanual response during the two-task condition reflects the dual-task interference. The interference occurred due to the interfering effects of the cognitive task representation rather than the mere additional responses required by the dual-task learning processes.

The interaction effects currently addressed in the literature have led to complications in designing a controlled experiment to explore the neural activation patterns in response to parallel processing as well. For instance, Nijboer *et al*. (2014) found that although there were differences between single-task and dual-task activation patterns, these patterns primarily resulted from task interactions, and they concluded that no specific multitasking area exists. In addition, Rothbart & Posner (2016) claimed that although the executive control areas of the brain, such as the frontoparietal cortex, are involved in multitasking, activation in these regions is not sufficient to explain the differences in the individuals' multitasking performance. Thus, the variability of neural activation patterns can be highly dependent on the nature of the assigned tasks as well as the design of the experiment.

*Brain Regions of Interest*

The regions of the brain that have been most robustly identified in parallel processing of multiple tasks are centered in the prefrontal cortex (PFC). Na *et al*. (2000) investigated the functional brain anatomy associated with visual and working memory. The researchers found that the memory stimulation tasks activated the PFC, and they concluded that the PFC plays a critical role in the central executive function of active maintenance of information. Other studies have also found that bilateral prefrontal and superior parietal cortices are especially active during visual working memory tasks (e.g. Voytek & Knight, 2010).

Feredoes *et al*. (2011) applied event-related TMS during functional magnetic resonance scanning (fMRI) to explore changes in functionally coupled brain regions during working memory maintenance. When the researchers presented distracters from different modality throughout working memory maintenance tasks, TMS did not hinder performance when presented to the regions that represented the distracter stimuli. They concluded that the dorsolateral prefrontal cortex (DLPFC)-driven control mechanisms increase the efficiency of working memory by successfully utilizing parallel processing mechanisms. Such mechanisms allow individuals to attend to relevant information in the presence of distraction. These findings demonstrate the strengths of analyzing neuroimaging techniques to offer physiological explanations to human behaviors, and they highlight the significance of conducting neuroimaging studies following behavioral studies to observe the complex brain networks at play in dual-task processing mechanisms.

### *Current Research*

This pilot study aims to expand the previous study by Schumacher *et al*. (2018) to find changes in neural activation patterns with the presence of dual-task interference that is predicted to result in greater involvement of PFC. We hypothesized that if PFC is responsible for actively maintaining information in the working memory, then when subjects are presented with one-task and two-task conditions, they will display increased PFC activation during two-task conditions to actively engage their limited working memory capacity.

We collected neuroimaging data using fMRI as well as behavioral data using reaction time. We presented the same stimuli sets that were used by Schumacher *et al*. (2018); for one-task (relational) condition, an image of a person and an image of a building together were mapped to one unique response that required coordination of two hands. During the two-task (independent) condition, an image of a person was mapped to a unique mapping of the left hand, and the image of a building was mapped to a unique mapping of the right hand. We had four pilot subjects who each came in for three session on three distinct days where the first two were dedicated to the collection of behavioral data in a mock scanner, and the final session was dedicated to the collection of neuroimaging data in the MRI scanner. Each session consisted of one practice trail and three experimental trials, and each trial contained both relative and independent tasks. Participants were asked to remember the unique response made with key presses with button boxes for both relative and independent tasks at the beginning of each trial and produce the correct mappings when visual stimuli were displayed on the screen.

We are currently in the process of conducting a whole-brain general linear model (GLM) analysis using Analysis of Functional Neuro Images (AFNI) for each participant to identify the regions of significant change in neural activity during the participants' responses to relative versus independent tasks. Group contrast maps will be then spatially normalized to a standard brain to display cortical regions of significant activity across participants. We expect to find significant increase in neural activation in PFC especially in the regions of DLPFC in the independent condition that requires dual information processing compared to relational condition that does not.

# METHODS

The present pilot study extended the previous study by Schumacher *et al*. (2018) that concluded that individuals experience dual-task interference when completing two tasks simultaneously. After the functional analysis of the collected neuroimaging data, we aim to identify the neural correlates underlying this effect.

Participants looked at a pair of visual stimuli that consisted of one image of a person and another image of a building simultaneously. During the independent tasks, the image of a person mapped to a unique key press on a button box using index and middle fingers of the left hand. The image of a building mapped to a unique key press on a different button box using index and middle fingers of the right hand. In contrast, during the relational tasks, each of the images alone did not map to a specific hand response. Rather, the combination of the two images mapped to a unique key press involving two button boxes with index and middle fingers of both hands. In other words, there was not a one-to-one mapping between the individual stimuli and responses. **Table 1** shows the mappings for the independent and relational conditions.

*Participants*

Participants were four students who volunteered through the Georgia Institute of Technology's School of Psychology SONA online platform. All participants were at least 18 years old, right-handed with normal vision, and no professionally diagnosed with neurological or psychiatric disorders. This study was carried out in accordance with the recommendations of the Georgia institute of Technology, Institutional Review Board.

| Independent Condition | | | | |
|---|---|---|---|---|
| | Left middle | Left index | Right middle | Right index |
| Face 1 x Place 1 | X | - | X | - |
| Face 1 x Place 2 | X | - | - | X |
| Face 1 x Place 3 | X | - | - | - |
| Face 2 x Place 1 | - | X | X | - |
| Face 2 x Place 2 | - | X | - | X |
| Face 2 x Place 3 | - | X | - | - |
| Face 3 x Place 1 | - | - | X | - |
| Face 3 x Place 2 | - | - | - | X |
| Face 3 x Place 3 | - | - | - | - |

| Relational Condition | | | | |
|---|---|---|---|---|
| | Left middle | Left index | Right middle | Right index |
| Face 1 x Place 1 | X | - | X | - |
| Face 1 x Place 2 | - | - | - | - |
| Face 1 x Place 3 | - | X | - | X |
| Face 2 x Place 1 | - | X | - | - |
| Face 2 x Place 2 | X | - | - | X |
| Face 2 x Place 3 | - | - | X | - |
| Face 3 x Place 1 | - | - | - | X |
| Face 3 x Place 2 | - | X | X | - |
| Face 3 x Place 3 | X | - | - | - |

**Table 1.** *Stimulus-response mappings for the two experimental conditions*. X in each column indicates the correct response given the stimulus pair presented.

The protocol was approved by the Institutional Review Board. All participants gave written informed consent in accordance with the Declaration of Helsinki.

*Stimuli*

Six grayscale male face images were used from the AR Face Database (Martinez & Benavente, 1998). Six grayscale images of buildings were also used. Three of each image types were randomly assigned to the independent and relational conditions. The difference between the conditions was that, for the independent condition, the left-hand, right-hand, and no responses were not associated with each other. In contrast, in the relational condition, the left-hand, right-hand, and no responses were determined by the pair of stimuli presented. For either condition, if the correct response was a key press with one hand and no response with the other, the response was categorized as unimanual. If the correct response was a key press with both left and right hand responses, the response was categorized as bimanual.

*Procedure*

Participants completed the study during the three sessions on three distinct days within one week at the GSU.GT Center for Advanced Brain Imaging (CABI). The first and second sessions involved participants completing the given tasks in a mock MRI scanner. After obtaining an informed consent on Session 1, each session began by informing the participants that they would perform two conditions. For each condition, two stimuli appeared simultaneously next to each other. A face stimulus appeared to the left of the fixation cross, and a place stimulus appeared to the right. Participants responded using two button boxes for both of the conditions; they used two buttons on each button box with their index and middle fingers. In the independent condition, they were told that each of the images on the screen maps to a unique button box response on each hand. In the relational condition, they were told that the images alone will not give a clue about the correct response; instead, each of the unique combinations of the two images maps to a unique button box response on both hands at the same time. Participants were asked to respond to each stimulus as quickly and as accurately as possible.

Sessions 1 and 2 were identical; each session included 6 blocks, and each block alternated between 3 relational condition sets and 3 independent condition sets. At the beginning of each block, the participants were given a self-paced answer key that showed correct button box key presses to all possible image pairs within the relational condition. The answer key was followed by a self-paced training procedure of 18 trials, and the correct feedback was displayed only when incorrect response was recorded by the participant. After the completion of the self-paced answer key and practice trials for the relational condition, the participants went through the same procedure with independent condition. Once the answer key and practice trials were completed for both conditions, the condition set composed of 18 trials began.

The screen displayed the participants' left- and right-hand accuracy and mean response time (RT) feedback after every block, and the feedback remained on the screen until participants were ready to begin the next block. Like the practice trails, participants also received feedback showing the correct mapping for 1000 ms after every incorrect trial. The participants proceeded to Session 3 only if their accuracy was 80% or above at the end of the Session 2. Session 3 was identical to Sessions 1 and 2 except that the participants performed the tasks in a real fMRI scanner rather than a mock MRI scanner. The scan time lasted about 60 minutes for each participant, and the total duration of the experiment, including the preparation time, was one and a half hours at most.

*Behavioral Data Analysis*

The mean RT data from Session 3 was analyzed to perform behavioral analysis. Trials with an incorrect response or less than 200 ms were removed from the analysis. The remaining data was analyzed using a 2 x 2 within-subjects ANOVA with Condition (relational vs independent) and Reponse (bimanual vs unimanual).

*Functional Data Analysis*

A whole-brain general linear model (GLM) analysis using AFNI will be conducted on the neuroimaging data collected from the pilot subjects in the fall semester. The GLM analysis will be conducted on each participant to identify the regions of significant activity change during the relational versus independent conditions. Group contrast maps will be then spatially normalized to a standard brain (Montreal Neurological Institute [MNI]) to observe the cortical regions showing significant activity across participants. Statistical parametric maps of t-values for each contrast will be thresholded at a corrected family-wise error rate of 0.05. This will be achieved by first setting an uncorrected p-value of 0.001 then applying a minimum cluster size of 32 voxels, as determined with Monte Carlo simulations using the program 3dClustSim. The clusters of significant activity will be used as regions of interest (ROIs) to test for differences between the groups. Data from these ROIs will be extracted and subjected to a 2 x 2 mixed ANOVA using SPSS to compare the conditions as a between-subjects factor and hand responses.

## RESULTS & DISCUSSION

Relational condition elicited a faster processing speed during unimanual responses (M=1199.995, SD=286.643) than bimanual responses (M=1280.598, SD=60.484), and the difference was significant (Figure 1, $F(1,14) = 8.920$, $p = .01$). The similar trend was seen in independent condition that also elicited a faster RT during unimanual responses (M=1018.147, SD=277.134) than bimanual responses (M=1312.705, SD=56.322), and the difference was significant (**Figure 1**, $F(1,14) = 8.749$, $p = .01$). This pattern indicates that making responses with two hands hinders performance than making responses with one hand.

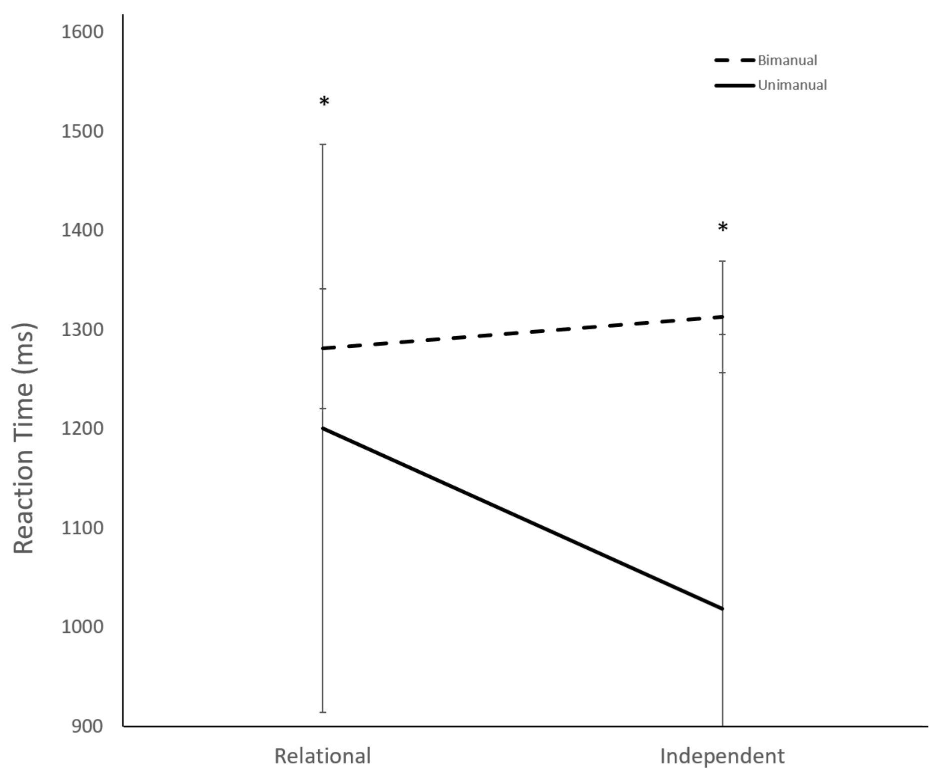


**Figure 1.** *Variation in Reaction Time Across Conditions*. The Session 3 behavioral data showed slower processing speed for unimanual tasks for both relational and independent conditions. Greater effect of hand responses was observed for independent condition.

When comparing the effects of Condition (relational vs independent) and Response (unimanual vs bimanual), however, different results were observed. Condition had a significant effect on the RT across Response; $F(1,7) = 9.078$, $p = .020$. This indicates that despite the similarity of stimuli displayed during relational and independent conditions, distinct patterns of behavior were utilized to respond to either one-task or two-task.

Response did not have a significant effect on the RT across Condition; $F(1,7) = 4.908$, $p = .062$. However, there was a significant interaction effect between the two variables; $F(1,7) = 28.885$, $p < .001$. When the participants used two separate mapping to identify a pair of images during the independent condition, they experienced a significant dual-task interference effect compared to when they used one mapping per pair of images during the relational condition. In other words, there was a greater decrease in performance when making two responses during the two-task condition than that during the one-task condition. This finding shows that the participants indeed used distinct cognitive representations across the two conditions, and this distinction can explain the variation in the participants' performance.

The behavioral data collected during Session 3 of this study showed similar trend that was seen in the behavioral study by Schumacher *et al*. The prior findings found significantly lower RT for bimanual response than unimanual ones during the independent tasks, and it did not find a significant difference in the mean RT for the bimanual and unimanual responses during the relational tasks (**Figure 2**). Overall, our data preserved the general trend as highlighted by Schumacher *et al*. by finding a non-significant response effect, significant condition effect, and significant interaction effect between the two variables.

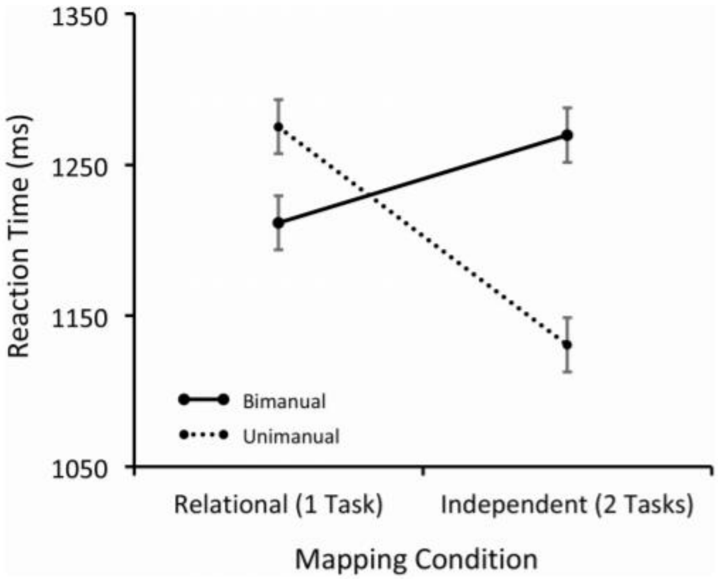


*Figure 2*. Behavioral Data by Schumacher *et al*.
Mean RTs were separated by the mapping and response conditions.

Although our behavioral data closely matched the trend observed by Schumacher *et al*., we believe that our experimental design replicated the prior study to a limited degree. Our sample size of four participant was smaller than that of sixteen participants that contributed to the prior study. We believe that, with continued collection of behavioral data from additional participants in the fall semester, we will be able to observe a clearer trend produced by the two variables. Additionally, Schumacher *et al*. collected data in a mock fMRI scanner and presented the behavioral data produced during the final session. Although our presented data was collected during the final experimental session as well, the collection occurred as the participants performed tasks in a real fMRI scanner rather than a mock. Although a mock scanner attempts to mimic the conditions of a real scanner, participants' performances may be affected by the notable differences between the mock and the real scanner to varying levels. After the data collection of four pilot subjects in the summer, the real fMRI scanner in the lab was upgraded before the data collection of additional subjects in the spring. One notable difference between the mock and the real fMRI following the upgrade was the size of the images that were displayed on the screen in the mock and the real scanners. The perceived size of the images in the mock scanner was about 1.5 times larger than that in the real fMRI scanner due to the differences in the screen resolutions. After discovering such huge discrepancy, we decided to not include the additional data collected from seven participants in the spring to this study. As this issue has already been resolved, it should not be a concerning factor as we continue to gather more data in the summer and fall semester.

In the summer, we will have more subjects participate in the study. We will collect sufficient behavioral data and neuroimaging data throughout the semester and analyze them in the fall semester. We expect to see similar behavioral trend that is observed in this study, and we predict to see increased brain activation in the PFC during bimanual responses in the independent condition. The regions of the brain that have been most robustly identified in parallel processing of multiple tasks are centered in the PFC, and the behavioral effects of dual-task interference can be explained by such brain activation patterns.

To conclude, the independent condition resulted in a greater dual-task interference than the relational condition when the participants made bimanual responses. The differences in the interference effect during the independent and relational conditions indicate that there are differences in the representations that the individuals make when responding to one-task or two-task stimuli. We hope to gain further insight in the structural and functional evidence with fMRI neuroimaging technique following this study. Identifying the behavioral and functional trends that demonstrate dual-task interference during two-task conditions can provide further support the argument that that parallel processing of dual tasks require executive processes. With better understanding of the brain regions involved in multitasking could allow us to continue to explore the cellular functions that contribute to such cognitive mechanisms and the ways we can expand our seemingly-limited parallel processing capacity.

# REFERENCES


Alzahabi, R., & Becker, M. W. (2013). The association between media multitasking, task-switching, and dual-task performance. *Journal of Experimental Psychology: Human Perception and Performance, 39*(5), 1485-1495. doi:10.1037/a0031208

Bentin, S., Kutas, M., & Hillyard, S. A. (1995). Semantic processing and memory for attended and unattended words in dichotic listening: Behavioral and electrophysiological evidence. *Journal of Experimental Psychology: Human Perception and Performance, 21*(1), 54-67. doi:10.1037/0096-1523.21.1.54

Deutsch, J. A., & Deutsch, D. (1963). Attention: Some theoretical considerations. *Psychological Review, 70*(1), 80-90. doi:10.1037/h0039515

Feredoes, E., Heinen, K., Weiskopf, N., Ruff, C., & Driver, J. (2011). Causal evidence for frontal involvement in memory target maintenance by posterior brain areas during distracter interference of visual working memory. *Proceedings of the National Academy of Sciences of the United States of America, 108*(42), 17510-17515. doi:10.1073/pnas.1106439108

Knoeferle, K., Knoeferle, P., Velasco, C., & Spence, C. (2016). *Multisensory Brand Search: How the Meaning of Sounds Guides Consumers' Visual Attention* (Vol. 22).

Li, H., Li, J., Li, N., Li, B., Wang, P., & Zhou, T. (2011). Cognitive intervention for persons with mild cognitive impairment: A meta- analysis. *Ageing Research Reviews, 10*(2), 285-296. doi:10.1016/j.arr.2010.11.003

Martinez, A., and Benavente, R. (1998). AR Face Database. CVC Technical Report, Vol. 24. West Lafayette: Purdue University.

Na, D. G., Ryu, J. W., Byun, H. S., Choi, D. S., Lee, E. J., Chung, W. I., Cho, J. M., & Han, B. K. (2000). Functional MR imaging of working memory in the human brain. *Korean journal of radiology*, *1*(1), 19-24.

Nijboer, M., Borst, J., van Rijn, H., & Taatgen, N. (2014). Single-task fMRI overlap predicts concurrent multitasking interference. *NeuroImage, 100*, 60-74. doi:https://doi.org/10.1016/j.neuroimage.2014.05.082

Pashler, H. (1994). Dual-task interference in simple tasks: Data and theory. *Psychological Bulletin, 116*(2), 220-244. doi:10.1037/0033-2909.116.2.220

Pew Research Center report (2018). Mobile fact sheet. http://www.pewinternet.org/fact-sheet/mobile/.

Schumacher, E. H., Cookson, S. L., Smith, D. M., Nguyen, T. V. N., Sultan, Z., Reuben, K. E., & Hazeltine, E. (2018). Dual-Task Processing With Identical Stimulus and Response Sets: Assessing the Importance of Task Representation in Dual-Task Interference. *Frontiers in Psychology, 9*(1031). doi:10.3389/fpsyg.2018.01031

Schwarb, H., & Schumacher, E. H. (2012). Generalized lessons about sequence learning from the study of the serial reaction time task. *Advances in Cognitive Psychology, 8*(2), 165-178. doi:10.2478/v10053-008-0113-1

Shiffrin, R. M., & Schneider, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending and a general theory. *Psychological Review, 84*(2), 127-190. doi:10.1037/0033-295X.84.2.127

Treisman, A. M., & Riley, J. G. (1969). Is selective attention selective perception or selective response? A further test. *Journal of Experimental Psychology, 79*(1, Pt.1), 27-34. doi:10.1037/h0026890

Voytek, B., & Knight, R. T. (2010). Prefrontal cortex and basal ganglia contributions to visual working memory. *Proceedings of the National Academy of Sciences, 107*(42), 18167. doi:10.1073/pnas.1007277107